METHOD FOR MAINTAINING MODE-LOCKED STATE OF FABRY-PEROT LASER IRRESPECTIVE OF TEMPERATURE CHANGE AND WDM LIGHT SOURCE USING THE SAME METHOD

CLAIM OF PRIORITY

This application claims priority to an application entitled "METHOD FOR MAINTAINING MODE-LOCKED STATE OF FABRY-PEROT LASER IRRESPECTIVE OF TEMPERATURE CHANGE AND WDM LIGHT SOURCE USING THE SAME METHOD," filed in the Korean Intellectual Property Office on March 5, 2003 and assigned Serial No. 2003-13574, the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to Wavelength Division Multiplexing (WDM) optical communications and, more particularly, to a method for maintaining the mode-locked state of a Fabry-Perot laser irrespective of the changes in peripheral temperature, and a WDM light source incorporating the same method.

2. Description of the Related Art

A WDM passive optical network (PON) generally provides high-speed, wideband communication services using unique wavelengths assigned to each subscriber. As such, the WDM-PON can secure communication confidentiality. Further, it can accommodate a

communication-capacity extension requested by each subscriber and easily extend the number of subscribers by simply adding unique wavelengths to be assigned to the new subscribers. Despite these advantages, the WDM-PON has not yet been put to practical use as it imposes a heavy economic burden on subscribers due to the need to provide a central office (CO) and each subscriber terminal with a light source of a specific lasing or oscillation wavelength as well as an additional wavelength-stabilization circuit for stabilizing the wavelength of the light source.

Accordingly, the development of an economical WDM light source is essential to realize the WDM-PON. To this end, a distributed feedback (DFB) laser array, a multi-frequency laser (MFL), a spectrum-sliced light source, and a mode-locked Fabry-Perot (FP) laser with incoherent light have been proposed. However, the DFB laser array and the MFL require a complicated manufacturing process and are costly. In addition, a wavelength stabilization and a correct wavelength selection of the light source are essential to implement the wavelength division multiplexing. Recently, the spectrum-sliced light source has been developed to provide a number of wavelength-divided channels by spectrum-slicing a broad-bandwidth optical signal through an optical filter or a waveguide grating router (WGR). For example, a light emitting diode (LED), a superluminescent diode (SLD), a Fabry-Perot (FP) laser, a fiber amplifier light source, and an ultra-short pulse light source have been proposed, and these elements do not require the spectrum-sliced light source to employ a light source of a specific lasing wavelength as well as additional equipment for achieving wavelength stabilization.

Proposed as a spectrum-sliced light source, the LED and SLD are not expensive and

also have a wide optical bandwidth. However, the LED and SLD are suitable for use as a light source for upstream signals having a lower modulation rate rather than downstream signals as they have a low modulation bandwidth and a low output power. The FP laser is a low-priced, high-output element, but has disadvantages in that it cannot provide a large number of wavelength-divided channels because of its low bandwidth, and its performance degradation due to the mode partition noise is serious when modulating and transmitting a spectrum-sliced signal at a high rate. The ultra-short pulse light source is coherent and also has a very wide light-source spectrum band, but its implementation is difficult as the lasing spectrum has low stability and its pulse width is only several picoseconds.

To address the deficiencies in the above light sources, a spectrum-sliced fiber amplifier light source has been proposed as a large number of high-power, wavelength-divided channels by spectrum-slicing ASE (Amplified Spontaneous Emission) light generated by an optical fiber amplifier. However, this light source must use an additional high-priced external modulator, such as a $LiNbO_3$ modulator, for allowing the channels to transmit data different from each other.

Another proposed light source is known as a mode-locked Fabry-Perot (FP) laser with incoherent light which produces a mode-locked signal. In order to produce the mode-locked signal, after a wide-bandwidth optical signal is generated from an incoherent light source, such as an LED or a fiber amplifier light source, through a waveguide grating router (WGR) or an optical filter, it is spectrum-sliced and then injected into an FP laser having no isolator. When a spectrum-sliced signal of a predetermined power level or more is injected into the FP laser, the FP laser generates and outputs only the light of a wavelength

coinciding with the wavelength of the injected signal. Such a mode-locked FP laser with incoherent light can perform data transmission more economically by directly modulating the FP laser according to a data signal.

However, a wide-bandwidth, high-power optical signal must be injected into the FP laser in order for the FP laser to output a mode-locked signal suitable for a high-speed, long-distance transmission. Further, in the absence of controlling external temperature, the Fabry-Perot laser mode is changed to another mode when the temperature varies. This mode change causes the Fabry-Perot laser to release from the locked state, escaping from a wavelength coinciding with the wavelength of the injected spectrum-sliced signal. Thus, the mode-locked Fabry-Perot laser cannot be adapted as a WDM light source. An external temperature controller (e.g., a TEC controller) is thus indispensable to adapt such a mode-locked Fabry-Perot laser when used as a WDM light source.

Fig. 1 shows the configuration of a conventional Fabry-Perot (FP) laser having a temperature controller. As shown, the conventional FP laser includes a TEC (Thermo-Electric Cooler) controller 1, a thermistor 2, an FP laser 3, and a TEC 4. The TEC controller 1 detects the temperature of the FP laser 3 through the thermistor 2 and controls the temperature of the FP laser 3 using the TEC 4.

The conventional FP laser, however, has an increased packaging cost because the thermistor and the TEC must be coupled to the FP laser, and the need to provide an additional TEC controller further increases the overall cost. These impose a high economic burden on subscribers, so that the WDM-PON has not yet been widely accepted.

SUMMARY OF THE INVENTION

The present invention has been made to overcome the above problems and provides additional advantages, by providing a method of maintaining the mode-locked state of a Fabry-Perot laser irrespective of the temperature change and an economical WDM light source using the same method. The inventive light source and its method allow the maintenance of the mode-locked state by an external light injection irrespective of the temperature change without requiring an additional temperature controller.

In one aspect of the present invention, a method for maintaining a mode-locked state of a Fabry-Perot (FP) laser irrespective of temperature change is achieved by generating spectrum-slicing incoherent light from a light source element and injecting the spectrum-sliced light to the FP laser. Then, only a lasing mode coinciding with the injected light's wavelength is amplified and outputted. Here, a lasing-mode interval of the FP laser is set to be less than a 3dB linewidth of the injected light, so that at least one lasing mode exists inside the 3dB linewidth of the injected light irrespective of the changes in external temperature.

Preferably, the lasing-mode interval of the FP laser exceeds half the 3dB linewidth of the injected light, so as to prevent two or more lasing modes from existing inside the 3dB linewidth of the injected light. The lasing-mode interval of the FP laser can be controlled by controlling the length of a laser cavity of the FP laser.

More preferably, the injected light has a left-right asymmetric spectrum with respect to a central wavelength thereof, so as to prevent two or more lasing modes from existing inside the 3dB linewidth of the injected light.

In another aspect of the present invention, a WDM (Wavelength Division Multiplexing) light source is provided and includes a light source element; a Fabry-Perot (FP) laser for amplifying and outputting only a lasing mode coinciding with a wavelength of light injected to the FP laser, while suppressing lasing modes not coinciding with the wavelength of the injected light; a WDM device for spectrum-slicing light generated from the light source element, for providing the spectrum-sliced light as the injected light to the FP laser, and for multiplexing a signal mode-locked by the FP laser; and a circulator for inputting the light generated from the light source element to the WDM device and outputting the signal multiplexed by the WDM device to a transmission link, wherein a lasing-mode interval of the FP laser is set to be less than a 3dB linewidth of the injected light, so that at least one lasing mode exists inside the 3dB linewidth of the injected light, thereby maintaining a mode-locked state of the FP laser irrespective of changes in external temperature.

Preferably, the lasing-mode interval of the FP laser exceeds half the 3dB linewidth of the injected light, so as to prevent two or more lasing modes from existing inside the 3dB linewidth of the injected light. The lasing-mode interval of the FP laser can be controlled by controlling the length of a laser cavity of the FP laser.

More preferably, the injected light has a left-right asymmetric spectrum with respect to a central wavelength thereof, so as to prevent two or more lasing modes from existing inside the 3dB linewidth of the injected light.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

Fig. 1 shows the configuration of a conventional Fabry-Perot laser having a temperature controller;

Fig. 2 shows the configuration of a WDM (Wavelength Division Multiplexing) light source employing a mode-locked Fabry-Perot (FP) laser according to a preferred embodiment of the present invention;

Fig. 3 illustrates a mode-locked phenomenon of a general FP laser;

Figs. 4a to 4d illustrate the wavelength change of the output light of the FP laser and the injected external light as peripheral temperature varies, in the case where a lasing or oscillation mode interval $\Delta\lambda$ of the FP laser is larger than a 3dB linewidth A of the injected light;

Figs. 5a to 5d illustrate the wavelength change of the output light of the FP laser and the injected external light as the peripheral temperature varies, in the case where the lasing mode interval $\Delta\lambda$ of the FP laser is less than the 3dB linewidth A of the injected light; and,

Figs. 6a and 6b illustrate the relationship between the lasing mode interval $\Delta\lambda$ and the cavity length of the FP laser.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, preferred embodiments of the present invention will be described in detail with reference to the annexed drawings. In the drawings, the same or similar elements are denoted by the same reference numerals even though they are depicted in different drawings. For the purposes of clarity and simplicity, a detailed description of known functions and configurations incorporated herein will be omitted as it may make the subject matter of the present invention unclear.

Fig. 2 shows the configuration of a WDM (Wavelength Division Multiplexing) light source employing a mode-locked Fabry-Perot (FP) laser according to a preferred embodiment of the present invention. The WDM light source 100 is capable of generating a wavelength-division-multiplexed optical signal to an optical transmission link 200 and includes an ASE (Amplified Spontaneous Emission) source 101, a circulator 102, an AWG (Arrayed Waveguide Grating) 103, and FP lasers 104.

As an incoherent light source having a wide linewidth, the ASE source 101 generates and outputs incoherent light to be injected into the FP lasers 104.

The circulator 102, including the first to the third ports, receives the incoherent light generated by the ASE source 101 through the first port and outputs the received light to the AWG 103 through the second port. At the same time, the circulator 102 receives WDM light mode-locked having incoherent light from the AWG 103 through the second port and outputs the received light to the transmission link 200 through the third port.

The AWG 103 is disposed between the circulator 102 and the FP lasers 104 and includes a single multiplexing port and N demultiplexing ports. The AWG 103 functions to

spectrum-slice an ASE beam inputted to the multiplexing port through the second port and then output the spectrum-sliced beams to the FP lasers 104, respectively. The AWG 103 further functions to multiplex the mode-locked light beams inputted from the FP lasers 104 and then output the multiplexed beam to the circulator 102.

The FP lasers 104 are connected to the N demultiplexing ports of the AWG 103 respectively, and output light beams mode-locked in response to the incoherent beams spectrum-sliced by the AWG 103. Prior to discussing the operation of the FP laser according to the present invention in detail, a mode-locked phenomenon of a general FP laser and the related influence of external temperature changes will be described hereinafter.

Fig. 3 illustrates the mode-locked phenomenon of a general FP laser. In this drawing, "10" denotes an optical spectrum of a general FP laser 40, "20" denotes a spectrum of external incoherent light inputted to the FP laser 40, and "30" denotes an optical spectrum of the FP laser 40 when it is mode-locked in response to the inputted external incoherent light.

As shown in the optical spectrum 10 of Fig. 3, in contrast to a distributed feedback (DFB) laser which outputs a single wavelength, the FP laser 40 outputs a plurality of lasing modes arranged at intervals of a specific wavelength, centered on a single wavelength, according to the gain characteristics of the material of the laser and the resonance wavelength of a laser diode. Upon receipt of the coherent or incoherent light as shown in the spectrum 20 from the outside, the FP laser 40 amplifies and outputs only a lasing mode coinciding with the wavelength of the injected light while suppressing lasing modes not

coinciding with the wavelength of the injected light, as shown in the spectrum 30.

If external temperature varies, the above FP laser releases from the mode-locked state in the case where it has no temperature control device in order to keep its operating temperature uniform. This is because the wavelength versus temperature change ratio of the FP laser is about 0.1nm/℃, while the ratio of the AWG used for spectrum slicing of the injected light is about 0.01nm/℃. Thus, the spectral overlap between the lasing modes of the FP laser and the injected light inevitably changes as the temperature varies.

Figs. 4a to 4d illustrate the wavelength change of the output light of the FP laser and the injected external light as peripheral temperature varies, in the case where a lasing mode interval $\Delta\lambda$ of the FP laser is greater than the 3dB linewidth A of the injected light. In Fig. 4a, "T_0" denotes the peripheral temperature, and it can be seen from Figs. 4b to 4d that, as the temperature increases by ΔT, the lasing wavelength of the FP laser is red-shifted. In Figs. 4a and 4d, the lasing mode, existing inside the 3dB linewidth A of the injected light, is mode-locked as denoted by a thick arrow. On the other hand, in Figs. 4b and 4c, the lasing mode does not exist inside the 3dB linewidth A of the injected light, where the mode-locked phenomenon disappears.

Accordingly, if it is possible to satisfy a condition in which the lasing mode of the FP laser always exists inside the 3dB linewidth A of the injected light even though external temperature varies, the mode-locked state of the FP laser can be maintained irrespective of the temperature change. Namely, the above condition is always satisfied in the case where the mode interval $\Delta\lambda$ of the FP laser is less than the 3dB linewidth A of the injected light.

Now, the teachings of the present invention will be explained with reference to Figs. 5 and 6.

Figs. 5a to 5d illustrate the wavelength change of the output light of the FP laser and the injected external light as peripheral temperature varies, in the case where the lasing mode interval $\Delta\lambda$ of the FP laser is less than the 3dB linewidth A of the injected light. In Fig. 5a, "T_0" denotes the peripheral temperature, and it can be seen from Figs. 5b to 5d that, as the temperature increases by ΔT, the lasing wavelength of the FP laser is red-shifted. In all cases of Figs. 5a to 5d, at least one lasing mode exists inside the 3dB linewidth A of the injected light, maintaining the mode-locked state, as denoted by a thick arrow. Thus, it can be seen that these cases of Figs. 5a to 5d are definitely different from the former cases of Figs. 4b and 4c which have no lasing mode inside the 3dB linewidth A of the injected light, disrupting the mode-locked phenomenon.

Referring to Figs. 2 and 5, the 3dB linewidth A of the injected light, spectrum-sliced by the arrayed waveguide grating (AWG) 103, is determined according to the characteristics of the AWG 103, and is generally about 40% of the channel interval of the AWG 103. It is thus possible to make the 3dB linewidth A of the injected light larger than the lasing mode interval $\Delta\lambda$ of the FP laser 104 by controlling the channel interval of the AWG 103. However, it is preferable that the linewidth of the injected light is not much larger than the linewidth of the lasing mode of the FP laser in order to attain the mode-locked phenomenon effectively. Control of the 3dB linewidth of the injected light is also restricted because the linewidth of the lasing mode of the FP laser has a relatively fixed

value.

Further, the lasing mode interval $\Delta\lambda$ of the FP laser 104 varies depending on its laser cavity length. Figs. 6a and 6b illustrate the relationship between the lasing mode interval $\Delta\lambda$ and the cavity length of the FP laser 104.

As shown in Fig. 6a, when the laser cavity length is d, the lasing mode interval $\Delta\lambda$ is expressed by the following equation:

$$\Delta\lambda = \lambda^2/2nd.$$

As shown in Fig. 6b, when the laser cavity length is 2d, the lasing mode interval $\Delta\lambda$ is expressed by the following equation:

$$\Delta\lambda = \lambda^2/4nd.$$

In these equations, λ and n denote the wavelength and refractive index, respectively.

In other words, if the cavity length of the FP laser increases twofold, the lasing mode interval is reduced by half. In this manner, it is possible to control the lasing mode interval by changing the laser cavity length.

Meanwhile, there may be a concern that two or more lasing modes are always caught inside the 3dB linewidth A of the injected light, in the case where the lasing mode interval $\Delta\lambda$ of the FP laser 104 is less than half the 3dB linewidth A (e.g., when $\Delta\lambda < A/2$).

Accordingly, it is preferable that the lasing mode interval $\Delta\lambda$ of the FP laser 104 is set to be more than half (A/2) of the 3dB linewidth A of the injected light and less than the 3dB linewidth A (i.e., $A/2 < \Delta\lambda < A$). Further, in such a particular case where two or more lasing modes exist inside the 3dB linewidth, there is a condition in which gain competition occurs between these modes so that only one of the modes oscillates or lases. Such a condition of allowing only the single mode lasing can be accomplished more effectively in the case where the injected light has a left-right asymmetric spectrum with respect to a central wavelength thereof.

As apparent from the above description, the present invention provides a method for maintaining the mode-locked state of a Fabry-Perot laser irrespective of changes in external temperature without using a temperature controller, and a WDM light source using the same method. The present invention has an advantage in that it is possible to realize an economical and efficient WDM light source that does not require a temperature controller, and a WDM-PON using the same light source.

Although the preferred embodiments of the present invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the invention as disclosed in the accompanying claims.